Generic Heading: Orthodontics

Title: Assessment of Growth in Orthodontics

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Assessments of Growth of relevance to Orthodontics

Abstract: Being able to accurately predict the likely timing and duration of growth, in particular the pubertal growth spurt, is important in orthodontic treatment planning. The different assessments of growth, their advantages and disadvantages will be described.

Clinical Relevance: A knowledge of the typical assessments of skeletal growth is important in the planning and execution of orthodontic treatment.

Objectives statement: To inform the reader of the methods of assessing skeletal growth

Growth can be defined as an increase in cellular size and number and can be linked with development, including an increase in specialisation or function[1]. It is certainly an important factor in orthodontics as it can both directly and indirectly influence treatment. The obvious direct effect is potential growth modification in both Class 2[2,3,4] and Class 3 skeletal cases[5,6]. Similarly, growth can have a direct and sometimes adverse effect on the occlusion and therefore delay treatment. For example a Class III skeletal pattern may become more severe, as might an anterior open bite. In such cases treatment may have to be put on hold until growth has essentially ceased. The presence or absence of growth may also have a less obvious and more indirect effect on orthodontic treatment. For example overbite reduction is often easier in the growing child and more recently it has been reported that the rate of active tooth movement is likely to be greater at times of rapid growth, particularly around the time of the pubertal growth spurt[7.]

, As part of an orthodontic assessment therefore, it is essential to consider the likely direction, magnitude and perhaps most importantly, the timing of growth in our patients. All children with a normal pattern of growth will undergo a pubertal growth spurt. For each individual, however, there are differences in the onset, duration, velocity and amount of growth over this period[8,9,10]. In an attempt to predict growth, in particular the timing of the pubertal growth spurt, a number of assessment methods have been described. These include chronological age, stage of dental development, the plotting of standing height measurement on growth charts, the stage of development of secondary sexual characteristics and radiographic measures of skeletal maturation.

At this point it is perhaps worth considering the properties of an ideal clinical growth assessment tool. These include:

- Easy to use
- Safe
- Accurate
- Reliable
- Valid
- Non invasive
- Cost effective

Successful treatment in the growing patient is often dependent on knowing the growth status of the particular individual. Therefore, an understanding of growth predictors and maturity indicators is paramount for the clinician. These will be discussed in turn.

Chronological Age

A number of variables including mental maturity, physical capacity, height and weight are sometimes estimated according to chronological age[11]. However, there can be wide differences between individuals of the same age, as a number of genetic and environmental factors, including nutrition, endocrine status, metabolic status and other medical conditions, can affect development[12]. Therefore, chronological age on its own cannot be used as a valid parameter to estimate facial growth or skeletal maturity[11].

Dental Development

Similarly it has been proposed that a link exists between dental development, skeletal age and chronological age[13]. A technique has been described whereby dental age is correlated with skeletal age using a radiological assessment of the degree of development of the root of the lower canine and its stage of eruption[14]. This method is however, controversial as dental eruption times can vary as a result of a number of both local and general factors, leading to observed differences between a patient's dental age, chronological age and degree of skeletal maturity. Although intraoral and radiographic assessments of the developing dentition, including degree of root formation, can be quickly and easily made, dental development indices are not reliable measures for predicting growth and skeletal maturity[8].

Growth Curves

In the 1920s Richard Scammon[15] proposed that the different tissues and systems of the body have different growth patterns and illustrated this by plotting the percentage of the final adult size of the four main tissues from birth to 20 years (Figure 1). These four tissue types were:

- Neural
- Somatic
- Genital
- Lymphoid

The somatic (general) curve describes the growth of the body as a whole, whilst the neural, genital and lymphoid curves are more tissue specific. The neural curve characterises the growth of the central nervous system and associated structures and shows that around 95% of neural growth is already attained by the age of 7 years. The genital curve describes the growth of the sexual characteristics. It shows slight growth of the primary characteristics in infancy, followed by a period of latency. Rapid growth then takes place during adolescence when both sexes develop their secondary sexual characteristics. Finally, the lymphoid curve describes the growth of the lymph tissues and associated structures. There is rapid growth of lymphatic tissues during infancy and early childhood, reaching a peak around the age of 11-13 years of age. The lymphoid tissue then declines during the second decade of life with shrinkage of the tonsillar tissue and thymus gland.

From the orthodontic perspective, maxillary and mandibular growth follows a pattern that is part way between neural and somatic growth, with the mandible following the somatic curve more closely than the maxilla.

Although useful in identifying the differential growth of the tissues, these Scammon curves cannot help predict when growth is going to occur.

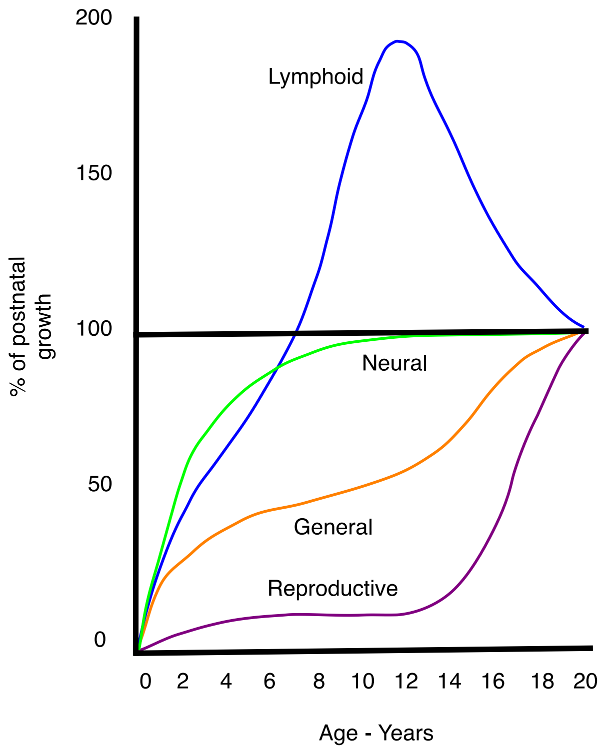

Figure 1. Scammon Growth Curves redrawn from *Scammon RE 1930 The Measurement of the Body in Childhood cited in The Measurement of Man JA Harris, CM Jackson, DG Patterson, RE Scammon pp 171-215 Minneapolis, University of Minnesota*.)

Height & Weight Characteristics

Longitudinal growth studies looking at various aspects of growth associated with childhood and adolescence[16,17] have been carried out in both North America and Europe. They have mostly concentrated on the height and weight characteristics of the individuals and the data collected has led to the development of growth charts. These charts can be used by parents, clinicians and researchers to plot an individual child's height and weight. They can also be used to describe the optimal growth for healthy children, compare children within a population, estimate adult height and assess puberty. An example of such a growth chart currently in use within the United Kingdom is the UK-WHO Growth Chart[18]. This comprises two charts which are gender specific and have been compiled using data from both the World Health Organisation child growth standards[19] and the UK 1990 growth reference for children[20]. Due to secular trends for increased height and weight, the UK-WHO Growth Chart has replaced those originally described by Tanner and Whitehouse in the 1960's and 1970's[21,22].

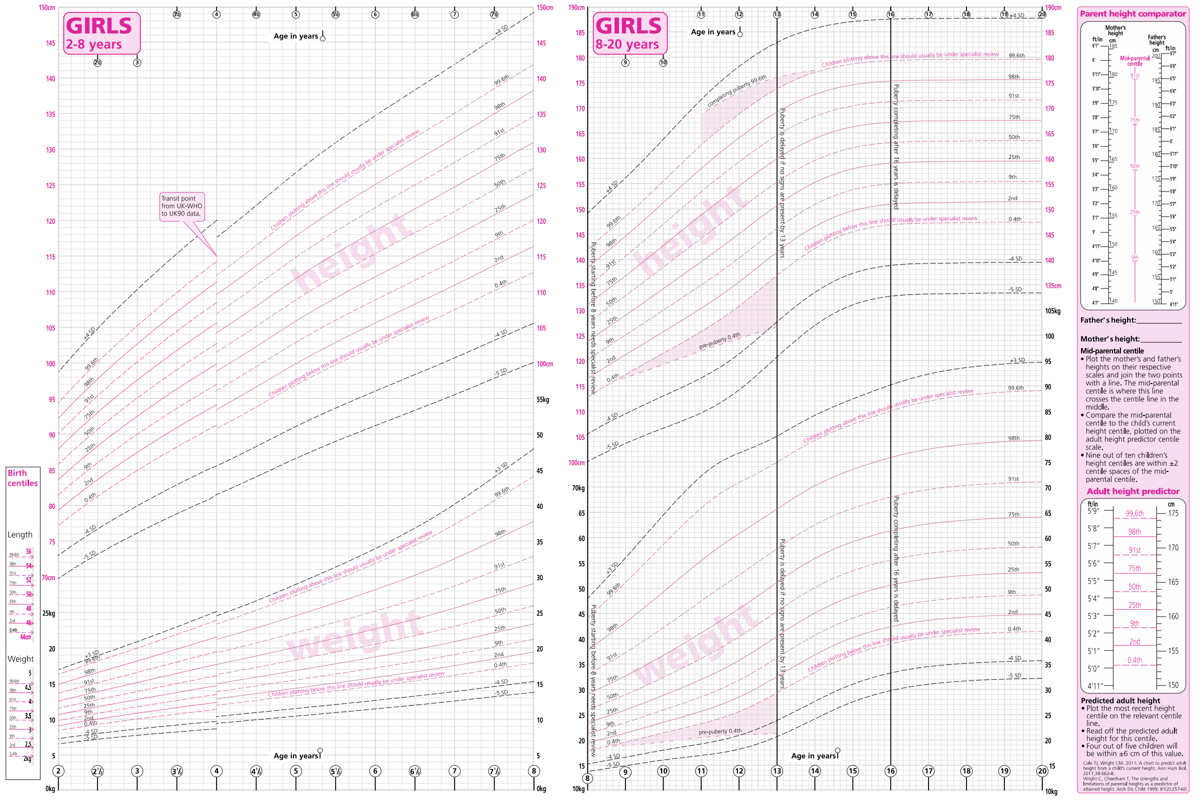

Figure 2: The UK-WHO Growth Chart for Girls (reprinted with permission from *WHO UK Growth charts, Girls 2-18,* http://www.rcpch.ac.uk/system/files/protected/page/NEW%20Girls%202-18yrs(4TH%20JAN%202012).pdf). © 2012/13 Royal College of Paediatrics and Child Health. A similar chart exists for males, which is coloured blue.

In orthodontics it is standing height rather than weight that is used in the assessment of growth. A correlation exists between changes in standing height and the onset of the pubertal growth spurt[23] Standing height measurement is easy to perform in the clinical setting, is minimally invasive, has no side effects and can be done on numerous occasions. The method of height measurement is standardised using a stadiometer. In order to take the measurement the subject should be standing (without shoes), their Frankfort plane should be horizontal (parallel with the floor) and whilst the subject breathes out a linear measurement is made from the floor to the top of the subject's head to the nearest millimetre (mm)[24] (Figure 3). The measurement obtained is then plotted on the gender specific UK-WHO Growth Chart. These age and sex specific height charts act as a reference tool for the average male/female and illustrate the wide range of individual variation, by including different lines representing different percentiles of the population. Therefore, if a child's plotted height measurement is found to be on the 5^{th} percentile line at a particular age, that child will be in the bottom 5% of the population for height. Or in other words, 95% of children of the same gender and age will be taller at that given time.

It has been shown that serial measures of a patient's height can be a clinically useful tool to predict the timing of the pubertal growth spurt[25], although due to individual variation it needs to be used with care[9].

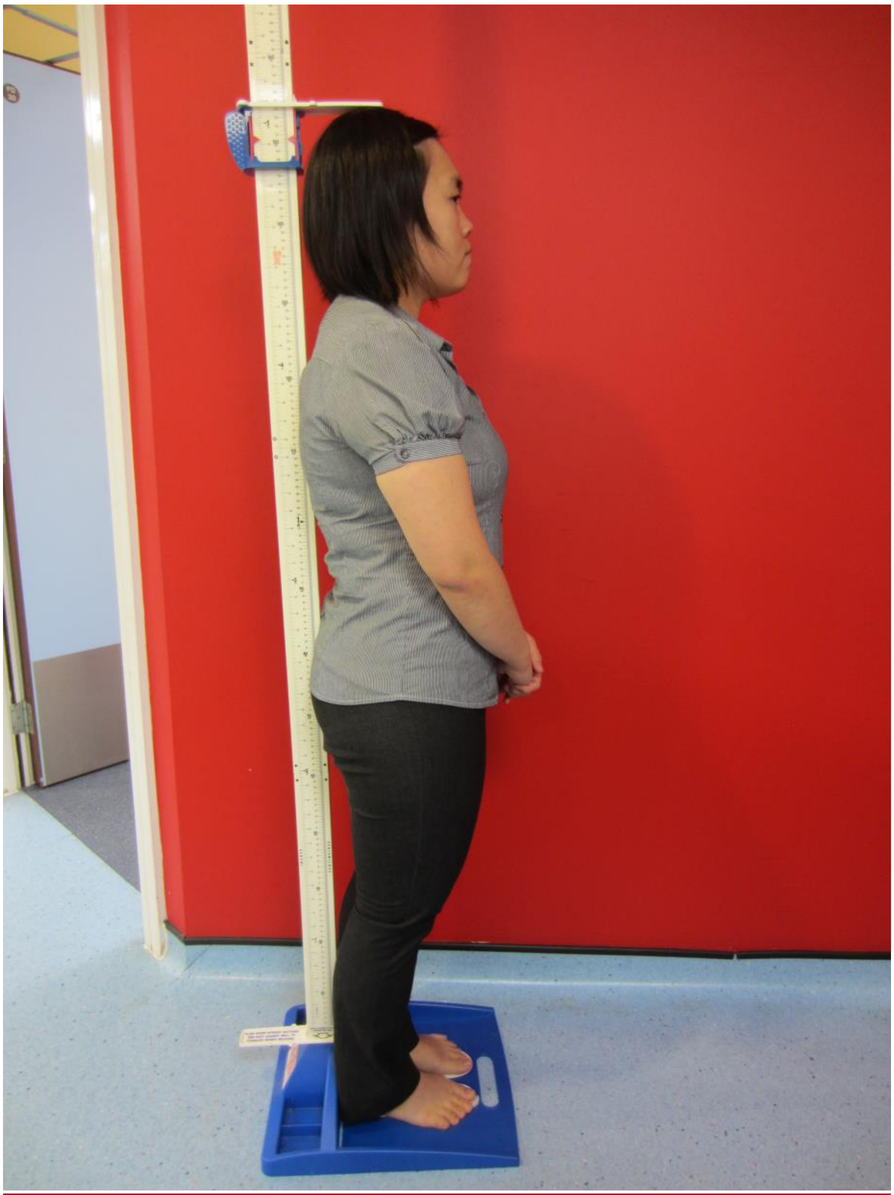

Figure 3. Measurement of standing height in a clinical environment using a stadiometer.

Growth Rate (Velocity) Curve

The growth rate or velocity curve is very different from a growth measurement curve, such as the UK-WHO Growth Chart, as it represents growth rate (*e.g.* centimetres per year) rather than a static height measurement at a particular time. A normal growth measurement curve may indicate that a child is still getting taller, whereas a velocity curve might show this is actually happening at a progressively slower rate. Conversely if the rate is seen to be increasing on a growth velocity curve it may indicate a child is beginning their pubertal growth spurt. The curve reaches a peak, known as the peak height velocity (PHV) at the time of the pubertal growth spurt (Figure 4) and it is at this point the maximum rate of growth has been reached. Following this there is a rapid decrease in the rate of growth, but it is important to understand the individual will still be growing, albeit at a much slower rate until it growth is complete. Longitudinal studies have shown that PHV varies for each individual, but usually follows pubertal onset by about 2 years. The pubertal growth spurt also occurs 2 years earlier in females than males and is summarised in Table 3[22].

Gender	**Pubertal Growth Spurt**	**Duration**
Female	12 years +/- 2 years	2 years
Male	14 years +/- 2 years	3.5 years

Table 3: Average Pubertal growth spurt age and duration for males and females

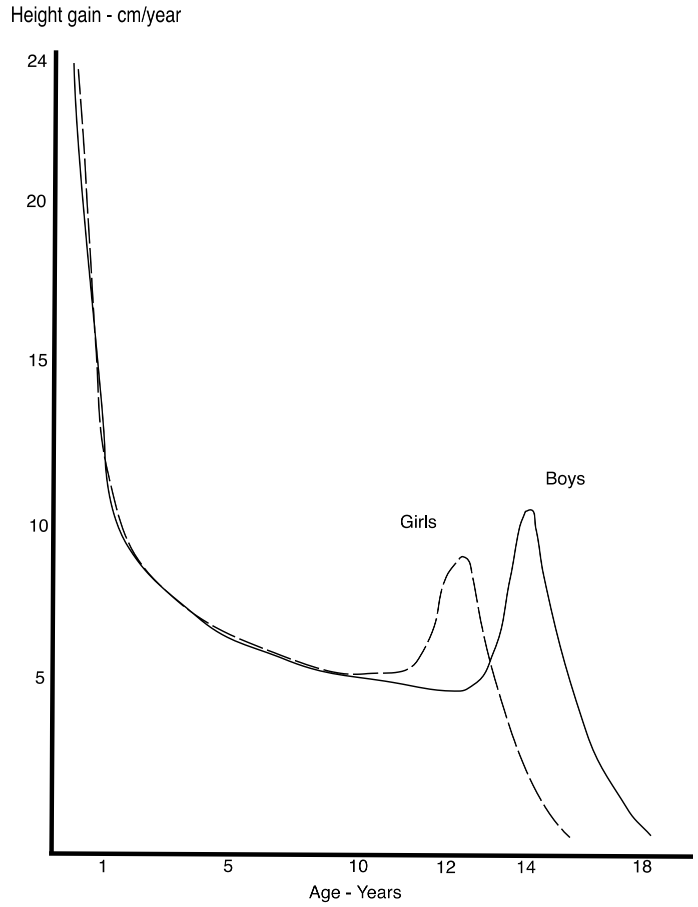

Figure 4. Peak Height Velocity Curve for Boys & Girls (redrawn from *Tanner JM, Whitehouse RH, Takaishi M. Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. Arch Dis Child. 1966 Oct;41(219):454-71.)*

Secondary Sexual Characteristics

The World Health Organisation has defined adolescence as the period between the ages of 10 and 18 years., It may be more appropriate however to consider the age ranges of 8 to 19 in girls and 10 to 22 years in boys as the limits of normal variation[26]. During this period most body systems become adult, both structurally and functionally.

Assessing whether an individual is undergoing puberty can be carried out by taking an appropriate history, or by carrying out a clinical examination. Signs and symptoms include the development of secondary sexual characteristics, growth of axillary/ pubic hair and in addition in girls, the onset of menarche and in boys the deepening of the voice and growth of facial hair. Some of these changes have been summarised in five stages and describe different periods of an adolescent's puberty.

- Stage 1: Pre-pubertal
- Stage 2 & 3: Undergoing puberty
- Stage 4 & 5: Completing puberty or puberty complete[27,28]

It is rare in orthodontics that we would wish to determine such personal information about our patients, particularly as other less intrusive and more reliable methods of predicting the puberty of an individual are available within our clinical environment.

Radiological Skeletal Assessment

A radiological assessment of the skeleton is considered to be the most reliable method of assessing skeletal maturity with respect to growth for orthodontic purposes[29]. Clinicians can accurately determine the different stages of growth using methods based on the indicators of skeletal maturation. Suitable regions for the assessment of skeletal maturity should be:

- Small in order to restrict the radiation exposure
- Have several ossification centres which ossify at different times
- Be easily accessible
- Use radiological views that can be standardised

A number of regions have been suggested for the purposes of such radiological assessment and these are outlined in Table 4.

Head & Neck	Skull Cervical Vertebrae
Upper Limb	Shoulder Joint/ Scapula Elbow Wrist Carpals Metacarpals Phalanges
Lower Limb	Femur Hip Joint Knee Ankle Tarsals Metatarsals Phalanges

Table 4: Anatomical regions normally used for skeletal maturation assessment

a. <u>Hand Wrist Radiographs</u>

The hand and wrist comprise a number of small bones that all show a predictable and uniform pattern of appearance, ossification and union from birth to maturity. Therefore, it is a region that has been extensively studied in relation to the assessment of growth.

The region is made up of 4 groups of bones, namely:

1. The distal ends of the radius and ulna
2. Carpals

3. Metacarpals
4. Phalanges

A number of methods have been described in the literature regarding the radiological assessment and prediction of skeletal growth using hand wrist radiographs[30,31,32]. One of the most popular was the publication of an atlas containing ideal photographs of hand-wrist radiographs of children of various chronological ages[30]. There are separate photos for males and females and the clinician matches their patient's radiograph with one of the photos in the atlas. For each radiograph, a chronological age corresponding to the skeletal age is assigned. This method can indicate the peak and end of growth, but cannot tell the clinician when the growth spurt is about to begin. Therefore, other evaluation systems were developed, which used similar radiographs and described discrete stages of hand-wrist development. These were characterised by specific stages of skeletal maturity ranging over the entire period of adolescence[31,32]. This makes it possible to assess whether a patient is early, pre-pubertal, pubertal onset, pubertal, pubertal deceleration or at the growth completion phase of skeletal maturity.

Other methods of assessing skeletal maturation have also been developed to aid clinicians who may not be familiar with, or confident in the interpretation of the anatomy and sequence of calcification of the bones of the hand. These methods include the appearance of the sesamoid ulnar bone in the metacarpophalangeal joint of the thumb, and/ or the capping between the epiphysis and diaphysis of the proximal and middle phalanges of the index and the middle fingers. Radiographic assessment of these areas can also be carried out using smaller periapical radiographs, thus reducing the radiation dose to the patient[33].

Despite suggestions that the use of hand wrist radiographs to establish the extent of skeletal development is an unreliable method for the prediction of the pubertal growth spurt[34], it is still an extremely popular method of growth prediction and is utilised in many countries around the World. In the United Kingdom however, the British Orthodontic Society Radiography Guidelines do not support the use of hand-wrist radiographs as it is deemed to unnecessarily expose the patient to additional radiation for little purpose[35].

b. Cervical Vertebrae:

In recent years there has been renewed interest in the use of the maturation of the cervical vertebrae as an assessment of growth. This is because these bones are readily visible on the lateral cephalogram, an X-ray that is routinely used in orthodontic clinical practice. Lamparski[36] initially developed such a system of skeletal maturation determination using the cervical vertebrae. The author described how the shapes of the individual and specific cervical vertebrae were found to be different at different stages of skeletal maturation and development.

This was further modified by Hassel and Farman[37], who described each stage of cervical vertebrae maturation (CVM) in much more detail and this was further refined by Bacetti *et al.*[38], who used longitudinal data to relate the cervical vertebrae changes to the increment in total mandibular length. They therefore developed a method of assessing the potential onset of the pubertal growth spurt. Bacetti and his team[38] describe six distinct and consecutive stages of assessment using the shapes of the cervical vertebrae C2, C3 and C4, which correlate to the peak mandibular growth and with a range of two years before and two years after it has occurred. They suggest that cervical stage (CS3) is the ideal time for orthodontic treatment, as the peak in mandibular growth will occur within a year after this particular observation.

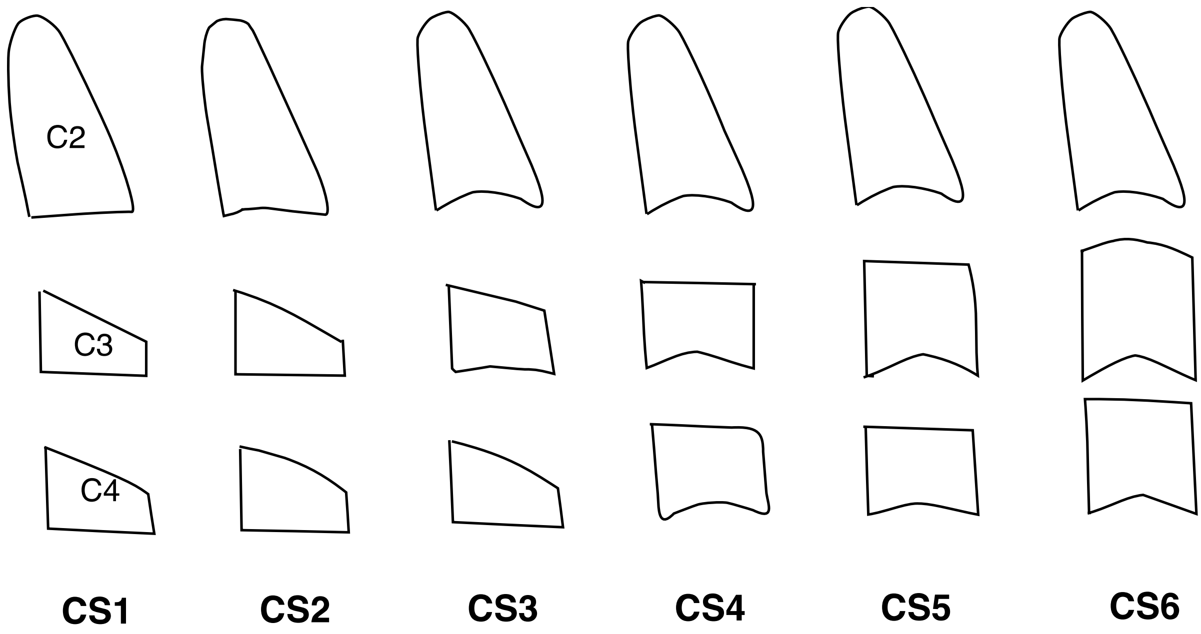

Figure 5: Schematic showing the six stages of CVM (Redrawn from Bacetti T, Franchi L & McNamara JA 2005 The Cervical Vertebral Maturation (CVM) Method for the Assessment of Optimal Treatment Timing in Dentofacial Orthopedics Seminars in Orthodontics; 11: 119-129)

Cervical Stage	**C2 – Lower Border**	**C3 – Lower border C3 - Body**	**C4 – Lower border C4 - Body**	**Peak Mandibular Growth**
1	Flat	Flat Trapezoid	Flat Trapezoid	On average 2 years after this stage
2	Concave	Flat Trapezoid	Flat Trapezoid	On average 1 year after this stage
3	Concave	Concave Trapezoid or rectangular horizontal	Flat Trapezoid or rectangular horizontal	During the year after this stage
4	Concave	Concave Rectangular horizontal	Concave Rectangular horizontal	Within 1-2 years before this stage
5	Concave	Concave Rectangular horizontal	Concave Rectangular horizontal	Finished at least 1 year before this

		or square	or square	stage
6	Concave	Concave Square or rectangular vertical	Concave Square or rectangular vertical	Finished at least 2 years before this stage

Table 5: The six cervical stages of maturation and their relation to peak mandibular growth

There is some doubt however, as to how reproducible this method is because of difficulties in classifying the shape of the vertebral bodies of C3 and C4[39]. Although this method may help inform the clinician when the peak of growth is going to take place, it does not inform the clinician how much growth is going to occur.

<u>Simple Questioning</u>

Sometimes just asking the patient or their parents about their child's growth can help the clinician to assess the stage of skeletal growth. Simple questions that can be asked at the consultation appointment that can aid diagnosis and treatment planning include:

- When did the child's shoe size last change?
- Is the child still getting taller?
- Is the child as tall as your Mother/ Father/ older siblings?

The advantage of this simple method is that although it is subjective, it will provide useful information about an individual's growth at the time. It will not necessarily provide information enabling an accurate prediction of growth *i.e*. whether the pubertal growth spurt is approaching, or is complete.

Secular Trends

Evidence suggests that children are growing faster now than their counterparts did in the past[40,41.] Data has shown that boys in the developed Western World have on average grown taller by ½ inch every ten years between 1873 to 1943[42]. These trends have also demonstrated that adolescents are not only growing faster, but they are also experiencing their pubertal growth spurt and completing growth much sooner than adolescents 100 years ago. Potentially this can be ascribed to better nutrition, balanced diets and better healthcare. More recently it has been shown that this secular trend has now started to plateau in the Western World. This is important in the context of the data from the literature that is used for the prediction of the pubertal growth spurt in individuals. The data in the majority of the longitudinal studies is over 50 years old and therefore needs to be considered in the context of current assessments.

Conclusions

There is no single method that can be used to accurately predict when an individual is about to undergo their pubertal growth spurt. Each method of prediction has its advantages and disadvantages. Growth is a fluid process and therefore a combination of a number of valid methods that complement each other will help the clinician confirm whether an individual is growing or not.

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